Measurements and numerical simulations of Sn ion stopping in low-pressure H_2 atmosphere

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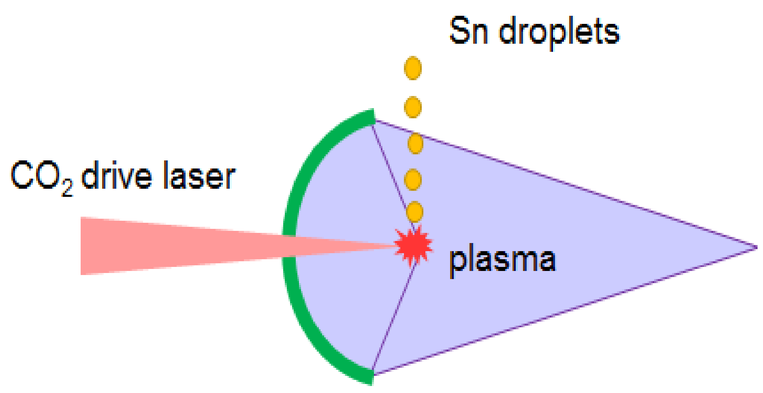
Motivation

EUV Source

Laser-produced plasma – EUV source for lithography

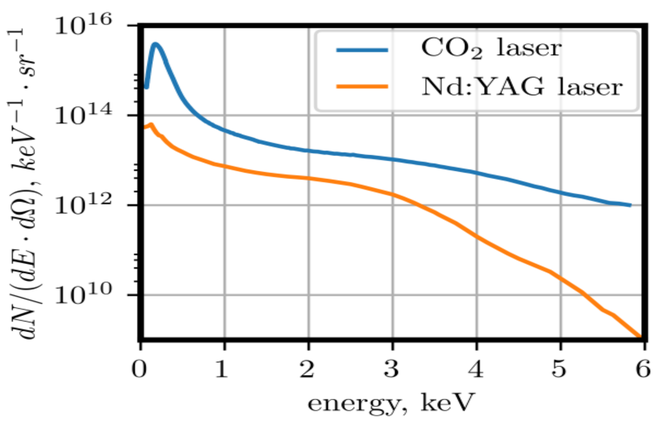


For details see:
Banine et al., J. Phys. D **44**, 253001 (2011)
Mizoguchi et al., Proc. SPIE **10097**, 1009702 (2017)
Fomenkov et al., Adv. Opt. Techn., **6**, 173 (2017)

Debris

Besides useful EUV photons, plasma also produces ion debris which is harmful for optical surfaces

Sn LPP ion spectrum



Debris mitigation

Ion debris mitigation relies on H_2 buffer gas

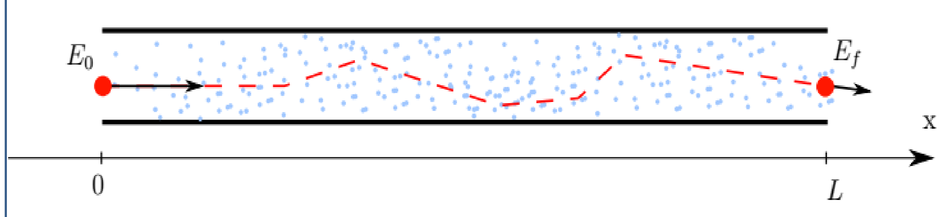
Energy losses of ions flying through a gas is quantified by collision cross-sections and integrally by the stopping power which is defined as

$$SP = -\frac{1}{n}\frac{dE}{dx}$$

Experimental data for SP of H_2 gas for Sn ions with relevant energies is not available up to know (to the best of our knowledge)

How to measure stopping power

Model situation - ions flying through a tube filled with gas:



SP can be derived using directly measured values:

- gas pressure distribution $p(x)$
- ion energy E
- ion time of flight t

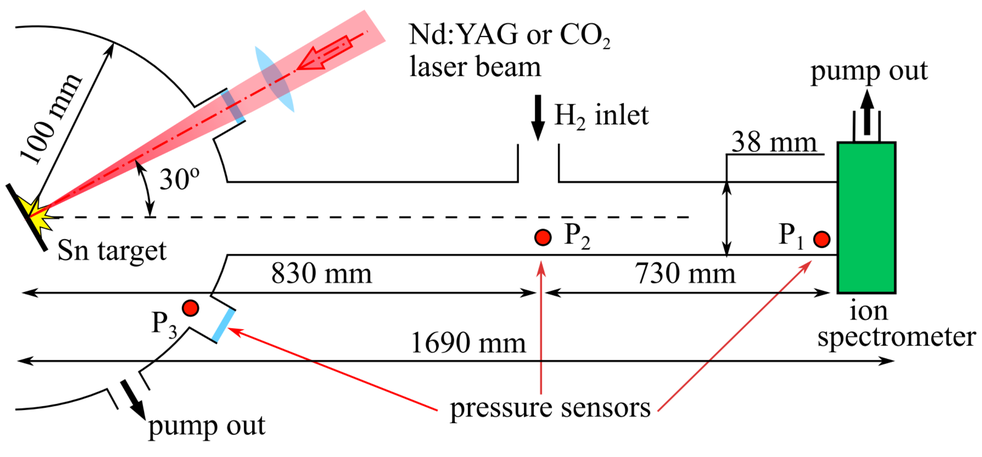
Main formulas

$$SP(E) = \frac{4Ek_BT}{p_{eff}L}\left(1-\frac{t}{t_{vac}}\right)$$

$$p_{eff} = \bar{p}\eta,\ \bar{p} = \frac{1}{L}\int_0^L p(x)dx,$$

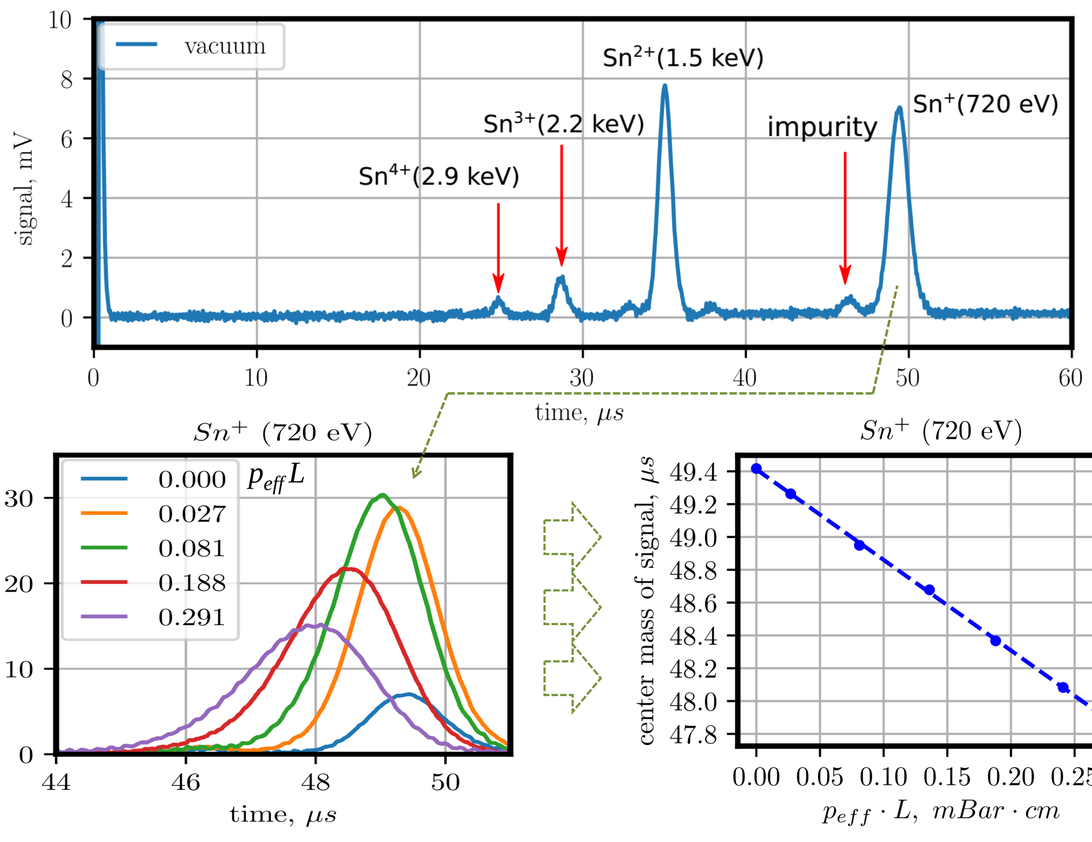
$$\eta = \frac{\bar{p}L^2 - \int_0^L\int_0^x p(x')dx'dx}{\bar{p}L^2/2}$$

Experimental setup

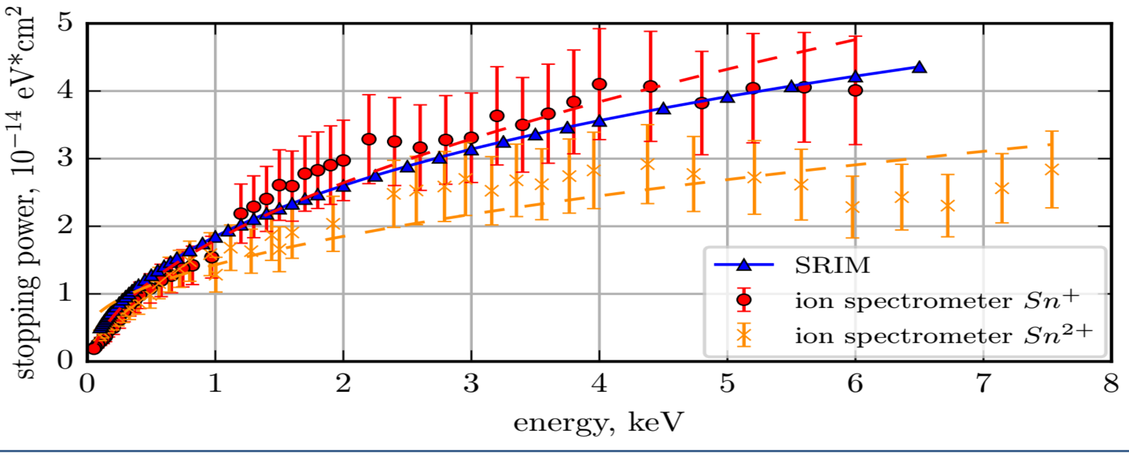


Experimental results

Example of signal from ion spectrometer



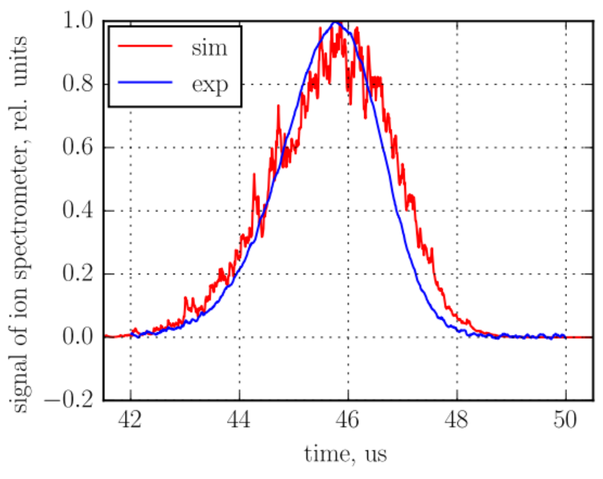
For a given energy E, measured ion signal vs $p_{eff}L$ gives SP



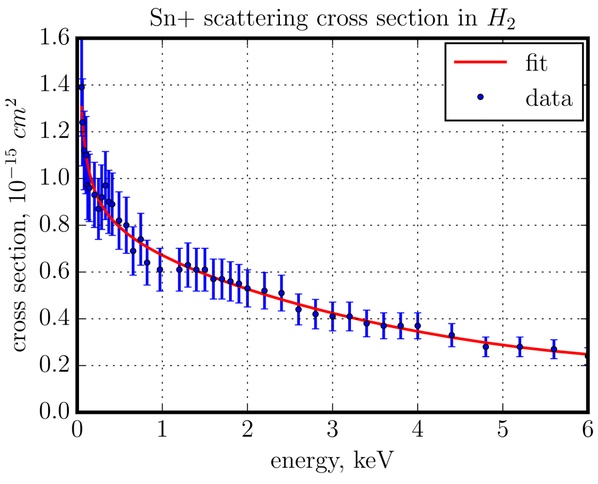
Particle-in-cell simulations

PIC code used to simulate ion flux in the gas tube. PIC simulations trace individual ions and use cross-sections to describe scattering acts. Using these simulations Sn^+-H_2 scattering cross-section was calculated by fitting ion signals.

Example of signal fitting



Calculated cross-section



Summary

- Experimental setup and method for gas stopping power for ions with ~0.1-10 keV measurements have been developed;
- H_2 stopping power for Sn^+ and Sn^{2+} has been measured;
- Surprisingly, measurements are close to SRIM predictions that are not valid in this ion energy range;
- Sn^+-H_2 scattering cross-section calculated by post processing of the measurements with PIC simulations;